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Social Perception of Public Water Supply Network and Groundwater Quality in an Urban Setting Facing Saltwater Intrusion and Water Shortages

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Abstract Perceptions developed by consumers regarding the quality of water reaching their household can affect the ultimate use of the water. This study identified key factors influencing consumers' perception of water quality in a highly urbanized coastal city, experiencing chronic water shortages, overexploitation of groundwater, and accelerated saltwater intrusion. Household surveys were administered to residents to capture views and perceptions of consumed water. Concomitantly, groundwater and tap water samples were collected and analyzed at each residence for comparison with perceptions. People's rating of groundwater quality was found to correlate to the measured water quality both in the dry and wet seasons. In contrast, perceptions regarding the water quality of the public water supply network did not show any correlation with the measured tap water quality indicators. Logistic regression models developed to predict perception based on salient variables indicated that age, apartment ownership, and levels of total dissolved solids play a significant role in shaping perceptions regarding groundwater quality. Perceptions concerning the water quality of the public water supply network appeared to be independent of the measured total dissolved solids levels at the tap but correlated to those measured in the wells. The study highlights misconceptions that can arise as a result of uncontrolled cross-connections of groundwater to the public supply network water and the development of misaligned perceptions based on prior consumption patterns, water shortages, and a rapidly salinizing groundwater aquifer.

Keywords Water quality perception · Public water supply · Groundwater · Saltwater intrusion

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Introduction

The availability and quality of water are of critical importance in arid and semi-arid regions, particularly in coastal urban areas, where major population centers are often encountered with continuous expansion despite limited access to sustainable freshwater resources. Unsustainable growth is invariably associated with chronic water shortages, particularly during the dry season, requiring additional water resources that often entail significant investments in new water supply projects. Major additional investments are needed to meet the United Nations Millennium Declaration towards access to improved water sources (Hutton and Haller 2004). Yet in many parts of the world, the rate at which new water sources are made available falls short of meeting the demand. As a result, consumers often rely on non-sustainable, unregulated, and/or untreated sources of water to meet their needs. In many regions, groundwater aquifers are pumped as a result of the popularization of the automatic submersible electric pump, cheap well-drilling techniques, and advancements in hydrogeology (Postel 2000; Llamas and Martínez-Santos 2005). Groundwater is estimated to provide more than 50% of the global drinking supplies, with 2.5 billion people depending solely on groundwater resources to satisfy their daily water needs (Zektser et al. 2005; UNESCO 2012). As such, in many coastal areas, pumping rates exceed the aquifers' safe yields promoting saltwater intrusion (Edwards et al. 2009; Gleeson et al. 2012; Döll et al. 2014) that poses significant threats of groundwater degradation on the long-term (Llamas and Martínez-Santos 2005), particularly in arid and semi-arid regions.

In water stressed regions, blending of public supply network distributed water with pumped groundwater often occurs instantaneously because of the prevalence of water storage tanks at the building level. These tanks are considered as local community-based adaptations to low public water supply network water pressure and frequent cuts in service (Celik and Muhammetoglu 2008). Thus residents are invariably left uninformed of the true source of water reaching their taps. The mixing of groundwater with the public water supply network can introduce physio-chemical and biological contamination (Tang et al. 2006). Moreover, it may change people's perception of the quality of the public supply water network and affect their trust in water authorities.

Public perception of water quality is reportedly a key factor that governs the use, willingness to pay, water conservation, pollution abatement, and trust in water utilities (McDaniels et al. 1998; Means 2002; Doria 2010; Rodriguez-Sanchez and Sarabia-Sanchez 2016). It tends to be often worse than what is suggested by actual water quality assessment (McDaniels et al. 1998; Lazo et al. 2000; Larson et al. 2009). As such, failing to quantify and/or dismissing public perception can be damaging towards the survival of modern water providers and has been linked to the worrying trend of consumers abandoning tap water in favor of bottled water, and the inability of utilities to fulfill their central mission of providing adequate supplies of acceptable-quality at a reasonable cost (Means 2002; Barraqué 2003).

The development of water quality perceptions is a complex process with many factors at play including organoleptic properties of the water, risk perception, socio-economic factors, geographical context, gender, environmental awareness, control over the water supply, previous experience, consumption rates, trust in the water provider, and/or media interchange (Smith et al. 1991; Syme and Williams 1993; Jardine et al. 1999; Turgeon et al. 2004; Doria et al. 2005, 2009; Dogaru et al. 2009; Doria 2010; Saylor et al. 2011). Previous work on quantifying the contribution of these factors towards the public's constructed perception has shown that while many of these pathways appear to be common across countries, the relative importance of each is often case-specific (Wakefield et al. 2001; Doria et al. 2009; Doria 2010). Brody et al. (2005) have also observed that water quality perception may exhibit spatial autocorrelation rendering general conclusions difficult at times with significant knowledge gaps in our understanding of how these factors interact to influence the public's perceptions in developing countries, where intermittent water supply may play an important confounding factor.

Besides eroding trust in governmental authorities, water quality perception can change priorities, influence societal practices, and hinder community decision-making regarding water use (Canter et al. 1993; McDaniels et al. 1998; Pahl-Wostl 2002; Turgeon et al. 2004; Doria et al. 2009; Saylor et al. 2011). In this context, this study examines people's perception of the quality of their public water supply network as well as their groundwater wells in a densely populated coastal pilot urban area that suffers from chronic water shortages, overexploitation of groundwater, unregulated pumping, as well as accelerated saltwater intrusion. Public perceptions are modeled as a function of salient socio-economic factors as well as measured tap and well water quality. Data for this study are based both on field survey results and on a concurrent water quality monitoring program. While several studies have attempted to correlate people's perception of their water sources to actual water quality measurements(Turgeon et al. 2004; Dogaru et al. 2009; Wedgworth et al. 2014), this work is the first to our knowledge that attempts to directly assess the impact of saltwater intrusion induced salinity on the public's perception of their water quality. The results should have wider implications to other water-stressed coastal urban centers engaged in the over-exploitation of groundwater aquifers. Moreover, this study, along with others, can help provide an improved perspective on the main factors that affect public perception of water quality in an urban environment within a developing country.

Materials and Methods

Study Area

The study area, which covers municipal Beirut in Lebanon (Fig. 1), is highly urbanized and densely populated. While the area is generally well connected to the public water supply network with acceptable quality (Ministry of Energy and Water 2010; Nasr et al. 2012), the public network is relatively old with much unaccounted for losses. The public water supply network for the study area is primarily fed from spring water (Jeita and Ain El-Delbeh) that is centrally treated and distributed. Slightly brackish groundwater wells are often used during the dry summer season to supplement dwindling spring water supplies (Amery 2000; Ministry of Environment 2011). Population growth, rapid urbanization, and poor water management have led to chronic water shortages (El-Fadel et al. 2000; Bou-Zeid and El-Fadel 2002; Yamout and El-Fadel 2005) that have forced water rationing with water distribution limited to 7–10 h every other day (El-Fadel et al. 2003). Water delivered through the public water supply network is particularly limited during the long dry season (June-

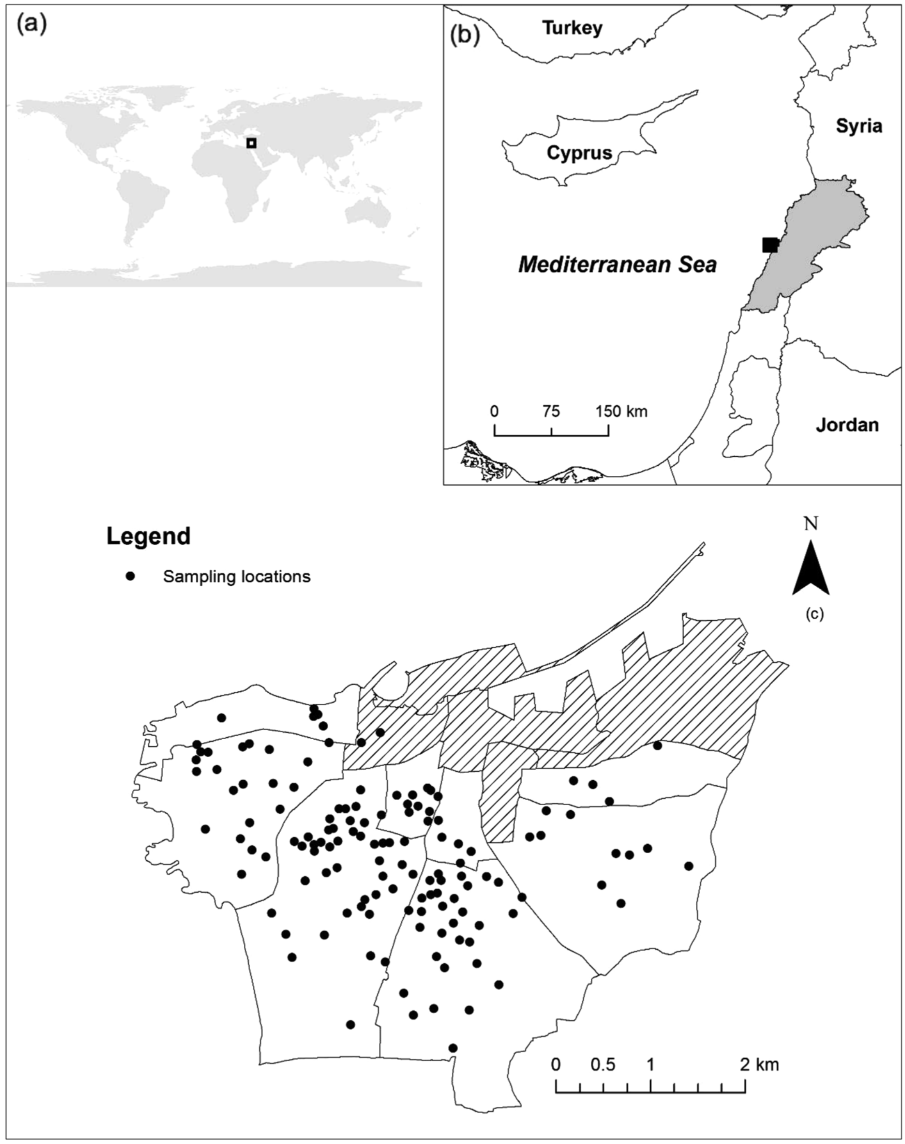

Fig. 1 Study area with well location (*dots*) and administrative units of the city. **a** shows the study area with regards to the world, **b** shows the study area in relation to the eastern Mediterranean area; **c** shows the sampling locations within Beirut

October) because of declining spring discharge and increased demand. The imbalance between supply and demand forced the local population to rely on water tankers (El-Fadel et al. 2014; Constantine et al. 2017) and/or drill illegal private wells that tap into a karstic aquifer with high permeability (Ministry of Environment 2011). The dominance of karst along the coastline of the pilot area increases groundwater vulnerability to seawater intrusion (Margane and Steinel 2011). As a result, the dependency of residents on groundwater extracted through unregulated private wells increases during the summer dry period (Ministry of Environment 2011). Increased pumping is expected to accelerate saltwater intrusion in the dry season affecting its quality. It can therefore be assumed that the tap water quality will be most affected by groundwater during the dry summer months. Given the prevalence of chronic shortages and the use of private wells, most consumers become unaware of the source of the water supply at their taps.

Household Surveys and Water Quality Analysis

The study area was divided into its 11 administrative zones (Fig. 1) in an effort to capture its various segments with respect to socio-economic differences, education, income, building age, etc. A stratified sampling approach was adopted to proportionally sample from each zone based on population density. Random samples of digitized and geo-referenced residential buildings were then selected from each zone. Household units within a chosen residential building were randomly selected. Buildings with no access to a private well and commercial buildings were excluded from the study sample. In the event of a non-response, rejection or inaccessibility, an adjacent building or household unit was selected. In total 310 buildings with private wells were visited, out of which 177 agreed to take part in the study.

Household surveys were administered through face-to-face interviews, using a questionnaire with open- and close-ended questions. The questionnaire targeted data and information about people's perception of water quality and the factors that could explain such perceptions, including household demographics and socio-economic indicators (refer to supplementary material). Specifically, residents were asked to express their satisfaction or dissatisfaction (yes/no) with the water quality of the public water supply network and their well groundwater. They were also asked to rate the water quality of their public network using an ordinal scale (good/average/bad). Satisfaction with water quality was assessed both in the dry (summer) and wet (winter) seasons to discern potential seasonal variations. Moreover, when dissatisfied, the reasons behind their dissatisfaction were probed.

Previous sampling from the public water supply network indicated that its quality complied with the World Health Organization (WHO) standards and its salinity levels did not exceed 200 mg/L (Nasr et al. 2012). In this study, water samples were collected from the tap of each household and from the building wells. Direct sampling of the public network water was not conducted because of immediate mixing with the well water at the household storage tanks. Three sampling campaigns were conducted to capture water quality variation within the year: (1) at the end of the wet (June 2013), (2) at the end of the dry (October 2013) season, and (3) during the wet season (April 2014) following an exceptionally dry year. Access to household taps and wells decreased marginally over time, as a result of respondents' survey fatigue. In total 372 groundwater samples (134 in June 2013, 124 in October 2013, and 114 in April 2014) and 345 water samples from the tap (128 in June 2013, 109 in October 2013, and 108 in April 2014) were collected. The samples were analyzed for several physical (temperature, conductivity and TDS), chemical (pH, Total Hardness (TH), alkalinity, chlorides, nitrates, sulfates, bromides, sodium, and potassium), and biological (total and fecal coliforms) indicators at the Environmental Engineering Research Center, American University of Beirut in accordance with Standard Methods for the Examination of Water and Wastewater (APHA AWWA WEF 2012).

Data Analysis

Water sample analyses were compared with the WHO water quality standards defined for domestic water uses (WHO 2011a). Seasonal changes in tap and well water quality were tested for statistical significance, using the repeated measures Analysis of Variance (ANOVA) test, given that the same wells were sampled over time. The test accommodates for within well and tap variability, while testing for inter-sampling variability. Pairwise *t*-tests with Holms's adjusted *p*-values were conducted to identify differences of significance between seasons. Additionally, statistical differences in sampled water quality were assessed as a function of people's perception using ANOVA. Water quality data on TH, chlorides, and TDS were subject to log transformation to ensure data normality. The Friedman Rank Sum Test, which represents the nonparametric equivalent of the one-way ANOVA with repeated measures, was used to analyze whether measured fecal and total coliform concentrations varied as a function of respondents' perceptions. The test accounts for built-in dependency in data, the presence of zeros, and right-censored data (too numerous to count (coliforms >700)). When the null hypothesis for the Friedman Rank Sum test was rejected, post-hoc comparisons were conducted to identify differences of significance between seasons. Concurrently, data and information collected using the household survey questionnaires were synthesized and analyzed to shed light on residents' perception regarding water quality.

Modeling public perception of water quality has been performed using a wide-range of statistical, quantitative, and psychological techniques. Structural equation models were developed to better understand and simulate water quality perceptions in Portugal and the United Kingdom as they relate to organoleptic and socio-economic contextual predictors and risk (Doria et al. 2005, 2009). In this context, generalized linear models have been developed to quantify the role that various salient factors had on changing the satisfaction probability of the public with regards to water quality (Turgeon et al. 2004; Dogaru et al. 2009; Doria et al. 2009; Wedgworth et al. 2014). Focus groups, survey research, mental models, and psychometric analysis have also been used to gain insight on the development of the public's perception (McDaniels et al. 1998; Doria et al. 2009; Saylor et al. 2011).

In this study, a series of logistic regression models (Eqs. 1 and 2) were developed to examine residents' satisfaction (Yes/No) with their public water supply network and well water quality based on several variables, including actual water quality, income, gender, age, educational level, geographic location (district), building age, frequency of water delivery, and season. The TDS was chosen to act as a proxy for groundwater salinization. TH and chlorides levels were not included since they exhibited strong correlations with TDS levels (0.86 and 0.98, respectively). Bacterial contamination was accounted for in terms of a dummy variable that differentiates between the presence/absence of FC contamination in the samples. All statistical analysis was conducted using the statistical software R (R Core Team 2015).

$$\mathrm{logit}(\mathrm{E}[Y_i|X_i]) = \mathrm{logit}(p_i) = \ln\left(\frac{p_i}{1-p_i}\right) = \beta * X_i, \quad (1)$$

$$p_i = \frac{e^{\beta X_i}}{1+e^{\beta X_i}}, \quad (2)$$

where Y_i is a binary variable (Yes or No) that indicates whether a respondent is satisfied or not with water quality, p_i is the probability of respondent i being satisfied with water quality, X is a matrix of predictors, and β is a vector of model coefficients. The use of logistic regressions to assess people's perception of their water quality is well established in the literature (Turgeon et al. 2004; El-Zein et al. 2006; Dogaru et al. 2009).

Results and Discussion

Field Surveys

The majority of surveyed residents (46%) had an "average" perception of their well water quality; the rest were equally split between perceiving it as "good" or "bad" (~27% for each). Overall, the public water supply network water was perceived to be of better quality than the well water (41.2% of residents rated it as good and only 8.8% as bad). The two main complaints reported by residents concerning their public supply network water were the presence of an odor other than that typically associated with chlorine followed by the hardness of the water (Fig. 2). Selecting odor as a primary reason for dissatisfaction with the water delivered by the public network confirms that organoleptics are an important factor for residents' satisfaction, consistent with other previous studies (McGuire 1995; Jardine et al. 1999; Jones et al. 2007; Doria et al. 2009; Doria 2010; Massoud et al. 2013; Rojas and Megerle 2013). Odor appeared to be a secondary factor as compared to hardness and salinity levels when it came to well water. The latter is known to cause a change in the taste of water (WHO 2003). It should be noted that reporting excessive hardness, salinity levels, as the main sources of discontent with well water and odor as the main source of dissatisfaction with the public water supply network, is not unique to Beirut. Hardness and total dissolved solids along with lead and chlorine were some of the most commonly cited chemicals responsible for public dissatisfaction (Mahler et al. 1999; Owen et al. 1999; Doria 2010). Nevertheless, geographical and cultural factors are known to modify this relationship. For instance, Lou et al. (2007) found that in Taiwan people's satisfaction with their water tend to increase with hardness. Few reported the presence of bacteria as a reason for their dissatisfaction, although bacterial contamination was found to be widespread in the collected tap and well samples. Wedgworth et al. (2014) reached a similar conclusion when analyzing perceptions in rural Alabama.

The water quality data showed that the majority of the tap and well water samples were characterized as brackish, highly brackish, or saline water (Table 1). Overall, the tap water quality can be considered better than the well water (Tables 1 and 2). While adverse health effects associated with increased TDS levels in drinking and domestic water are not well documented, the palatability of water is rated as poor when TDS levels exceed 900 mg/L (WHO 2003). Similarly, a salty taste is noticeable when chloride levels exceed 250 mg/L (USEPA 2015). The vast majority of samples exhibited concentrations above those guidelines (Table 1). In addition, 98.7% of samples were categorized as very hard, with levels consistently exceeding the 180 mg/L threshold (Briggs and Ficke 1977; McGowan 2000). Elevated hardness is known to cause scaling and corrosion in water appliances and pipes (WHO 2011b). Both tap and well water exhibited significant bacterial contamination with more than 90% of the collected well samples having TC across the three sampling rounds, while FCs were recorded in ~20% of sampled wells. Samples collected from the tap were also contaminated with TC more than 83% of the time and with FC more than 17% of the time.

The satisfaction with the public water supply network and well water exhibited seasonal differences. More than 75% of households reported dissatisfaction with their well water quality during the dry season in comparison to 70% during the wet season. On the other hand, 60% of households who received public network water reported dissatisfaction with its water quality in the summer as compared to 43% during the winter. Satisfaction levels with the water distributed by the public network contrast sharply with those determined in areas served by the same water establishment but receiving enough water to avoid illegal groundwater pumping. In those areas, satisfaction exceeded 70% (Nasr et al. 2012). Differences in tap and well water quality were observed across the three sampling rounds (Fig. 3). Statistically significant differences (p-value <0.05) were found for TDS levels between the wet season in 2013 on one hand and the dry 2013 season and the 2014 wet season on the other, both for tap and well water samples. Chloride levels were statistically different across the three sampling dates for both tap and well water samples. No statistical differences were found for total hardness in the groundwater samples across the three sampling rounds; yet hardness in the tap water samples appeared to have increased between the first sampling round and the latter rounds. Bacterial contaminations statistically (Friedman's test p-value <0.05) increased over the three sampling

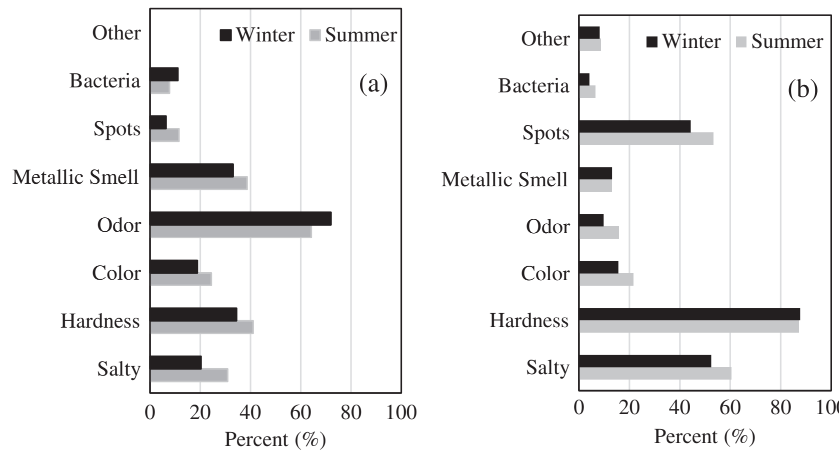

Fig. 2 Reported reasons for dissatisfaction with water quality **a** public water supply network and **b** well water during wet and dry seasons

Table 1 Measured salinity and hardness concentrations in well and tap water samples

	Oct 2013	Jun 2013	Apr 2014	Oct 2013	Jun 2013	Apr 2014
	Percent of tap water samples exceeding threshold (%)			Percent of well water samples exceeding threshold (%)		
TDS (ppm)[a]						
Drinking water (0–500)	8.1	15.0	0.8	0	0	0
Fresh water (501–1000)	20.5	33.1	14.6	17.2	33.1	7
Brackish water (1001–5000)	46.4	36.1	50.76	38.3	43.2	47.2
Highly Brackish (5001–15,000)	19.6	12.0	23.84	34.4	18.7	32.4
Saline water (15,001–30,000)	5.4	3.8	10	10.1	5.0	13.4
Total hardness (mg/L)[b]						
Soft (0–60)	0	0	0	0	0	0
Moderately hard (61–120)	0	0	3.8	0	0	0
Hard (121–180)	0	0	2.3	0	0	0.07
Very hard (>180)	100	100	93.9	100	100	99.3
Chlorides (mg/L)[c]						
No salty taste (<250)	20.5	36.7	30.3	14	31	27.5
Salty taste (≥250)	89	63.3	69.7	86	69	72.5

[a] Bridge and Demicco (2008)

[b] World Health Organization (2011b)

[c] World Health Organization (2003)

rounds for TC and FC in well and tap samples; only FC concentrations in the tap water collected between October 2013 and April 2014 were statistically similar.

Comparing the perception that residents had regarding the quality of the public water supply network against the actual tap water quality (represented by TDS, TH, chloride, and bacterial levels) indicated that perceptions were statistically independent of the actual water quality (repeated measures ANOVA p-values >0.05). On the other hand, respondents' perceptions of the groundwater correlated well with measured well water quality. Conditional on respondents' rating, statistically significant differences were discerned for hardness, chlorides, and TDS levels in well samples across the three sampling rounds. During the wet season, the highest median TDS, TH, and Cl^- concentrations were found in well samples that were ranked as "Poor" by respondents; the lowest median concentrations were found in wells where respondents ranked the well water as "Good" (Fig. 4). Similarly in the dry season, residents that rated their well water quality as "Good" tended to have lower median levels of TDS, Cl^-, and TH than those who ranked the well water as "Average". Interestingly, no resident who ranked the well water quality as "good" complained about the quality of the public water supply network. Similarly, only 19% of those who rated the well water as "Poor" had a positive view of the quality of their public water supply network. The results suggest that residents' perceptions of the public water supply network are affected by the inferior water quality from unregulated wells. The concurrent consumption of groundwater from

Table 2 Tap and well water quality in the pilot area

Season	June 2013			October 2013			April 2014			WHO (2011b) Threshold
Parameter	Min	Max	Median	Min	Max	Median	Min	Max	Median	
Tap										
TDS (ppm)	101	22,224	1280.5	102	25,221	1901	422	33,385	2413.5	600
Cl^- (mg/L)	5	13,080	390	62	17,330	1105	7.8	19,750	1212.5	300
TH (mg/L as $CaCO_3$)	87	8740	830	54	8010	830	90	9440	1008	–
Total coliform (cfu/100 ml)	0	TNTC	30	0	TNTC	142	0	TNTC	178	0
Fecal coliform (cfu/100 ml)	0	TNTC	0	0	TNTC	0	0	TNTC	0	0
Well										
TDS (ppm)	560	23,414	2331	533	31,553	3782	775	32,220	4615	600
Cl^- (mg/L)	100	13,080	617.5	100	17,670	2120	35.4	19,030	2655	300
TH (mg/L as $CaCO_3$)	309	8740	1169	262	12,320	1150	131	9440	1340	–
Total coliform (cfu/100 ml)	0	TNTC	75	0	TNTC	106	0	TNTC	194	0
Fecal coliform (cfu/100 ml)	0	TNTC	0	0	TNTC	0	0	TNTC	0	0

TNTC Too Numerous To Count

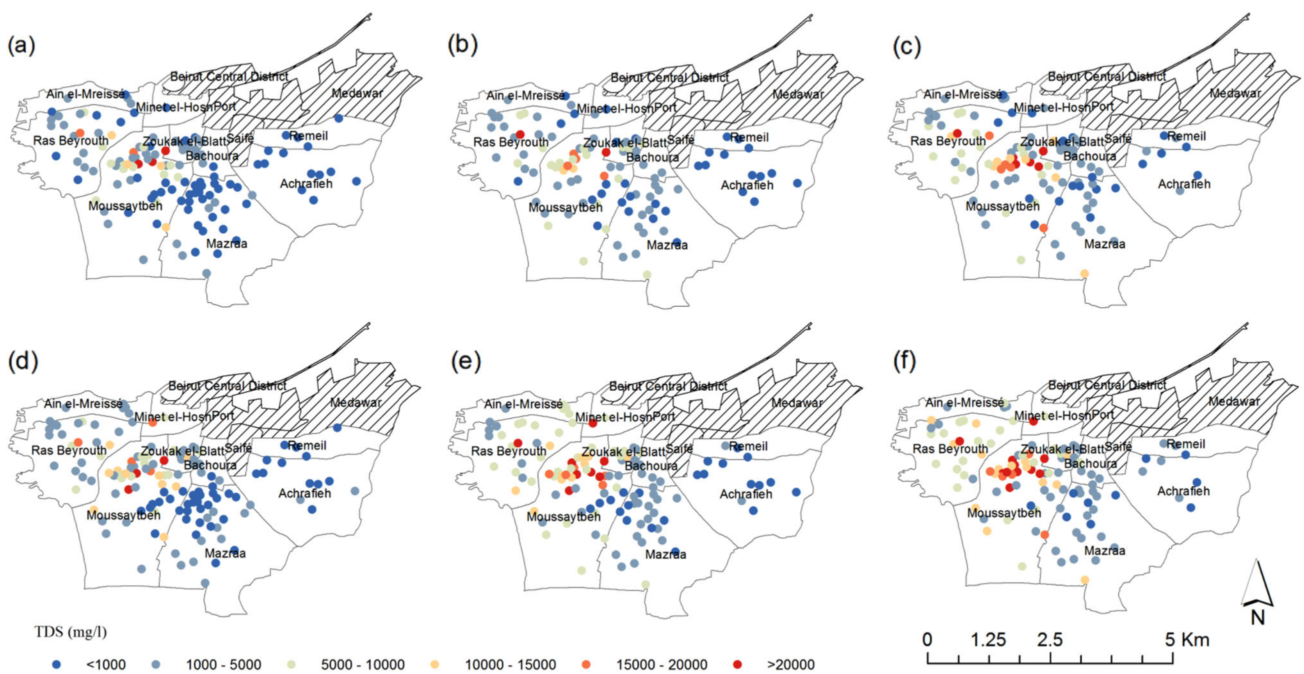

Fig. 3 Tap (T) and Well (W) TDS levels T: **a** June 2013, **b** October 2013, **c** April 2014, W: **d** June 2013, **e** October 2013, **f** April 2014

wells, which often is subpar in its quality, may promote the formation of a persisting negative experience towards the public water supply. Further details on the role that prior experience plays in building perceptions can be found in Doria (2010).

Factors Influencing Satisfaction with Water Quality

The satisfaction of residents with the water quality of their public network proved to be independent of the measured tap water quality, public water supply network delivery

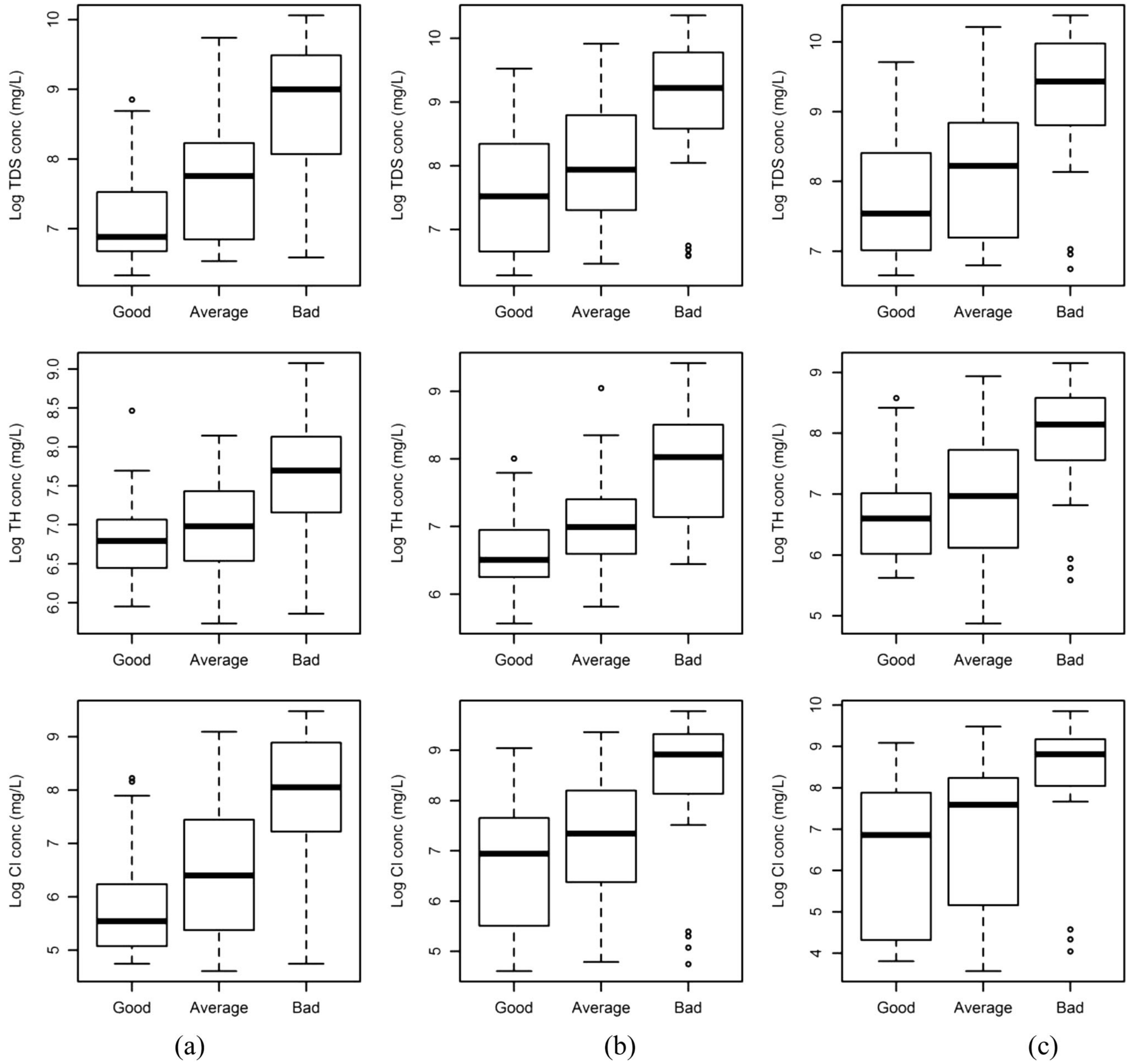

Fig. 4 Well water quality as a function of people's perception of their well water Quality is assessed in terms of total dissolved solids (TDS), total hardness (TH), chlorides (Cl). **a** Wet season (June 2013), **b** Dry season (October 2013), **c** Wet season (April 2014)

rates, and salient socio-economic predictors. Oddly, the only significant predictor of public water supply network satisfaction was TDS levels of wells during the dry period. The residents' satisfaction with the quality of their public supply network increased by 1.5 times when TDS levels in wells decreased by ~6000 mg/L. No such relationship was apparent during the wet season. The results highlight that the respondents' perception of the public water supply network exhibits a poor correlation with the actual water quality. This divergence is understandable, given that people's judgment is based on a complex mental construct that account for risk perception, trust in the public establishment, socio-economic status, organoleptic indicators, prior experiences, media, and contextual indicators (McDaniels et al. 1998; Lazo et al. 2000; Larson et al. 2009; Doria 2010). The perception towards the quality of the public water supply network was found to be independent of its actual water quality and was largely driven by mistrust towards the local water establishment and the inability of residents to differentiate between the public network water and well water reaching the building tap. As a matter of fact, frequent changes in the quality of the tap water resulting from blending pumped brackish groundwater with the intermittent public water is expected to play a role in reducing the acceptability of the public water. Syme and Williams (1993) reported that the water quality acceptability dropped as respondents experienced an increasing variability in the quality of their tap water. In contrast, people's satisfaction with the well water appears to be governed by the actual water quality of the well as well as the age of the respondent, the season, and the apartment ownership (Table 3). The coefficient on TDS values was negative (−0.97 for the dry season and −2.76 for wet season), suggesting that respondents whose well water recorded higher TDS values were more likely to be unsatisfied with the well water quality. The coefficient associated with age proved to be positive (0.05), indicating that older residents are more likely to hold significantly better perceptions about the well water quality in comparison to younger residents. Additionally, tenants tended to be more satisfied with the well water quality as compared to landlords (Table 3).

On average the odds of an apartment owner, who is 20 years old and whose well water has a TDS of ~5200 ppm (the average well TDS in the study area), being satisfied with his/her water quality was only 2%. Older respondents expressed a higher satisfaction as compared to their younger counterparts. This association may reflect that younger respondents tend to be more environmentally aware and have higher expectations and a better appreciation of the damages that salinity can have on infrastructure, home appliances, hair/skin and clothing. Note that previous work has been inconclusive with regards to the association between age and public water quality perceptions and environmental risks (Doria 2010). While several studies reported on the important role that age plays in developing public perceptions (Syme and Williams 1993; Gorden 2000; Park et al. 2001; Parkin et al. 2001; Turgeon et al. 2004), others reported no association (Dogaru et al. 2009). On average the satisfaction odds ratio (OR) increased by a factor of ~1.6 for each ten additional years in age. These findings are consistent with those of Hu and Morton (2011), when assessing water quality perception in the US Midwest.

Renters tended to have a higher satisfaction rate than owners under the same conditions (Fig. 5). The renter's satisfaction odds ratio was 2.4 times higher than the odds of an owner with a similar age and exposed to the same TDS levels. This could reflect the minimal attachment that tenants have towards their residence as well as their ability to change residence at will. Additionally, owners and not renters have to repair damages caused by high salinity. Previous work in Portugal and the United Kingdom also identified that house ownership had an influence on developing water quality perceptions (Doria et al. 2009).

Correlations between educational level, household monthly spending, gender, monthly household income, and the presence of advanced building level treatment (e.g.

Table 3 Logistic regression for perceptions of well water quality

Model results	Estimate	SE	*p*-value
Intercept	−3.82	0.66	<0.05
TDS dry[a]	−0.97	0.45	<0.05
TDS wet[a]	−2.76	0.58	<0.05
Age of respondent[b]	0.05	0.01	<0.05
Occupants: Tenants	0.86	0.43	<0.05
Model fit:			
McFadden pseudo R^2	0.48		
Cragg and Uhler's pseudo R^2	0.68		
Maximum likelihood pseudo R^2	0.57		

[a] TDS values were scaled by the mean and the standard deviation of measured TDS values

[b] Respondent age were centered around 20 years

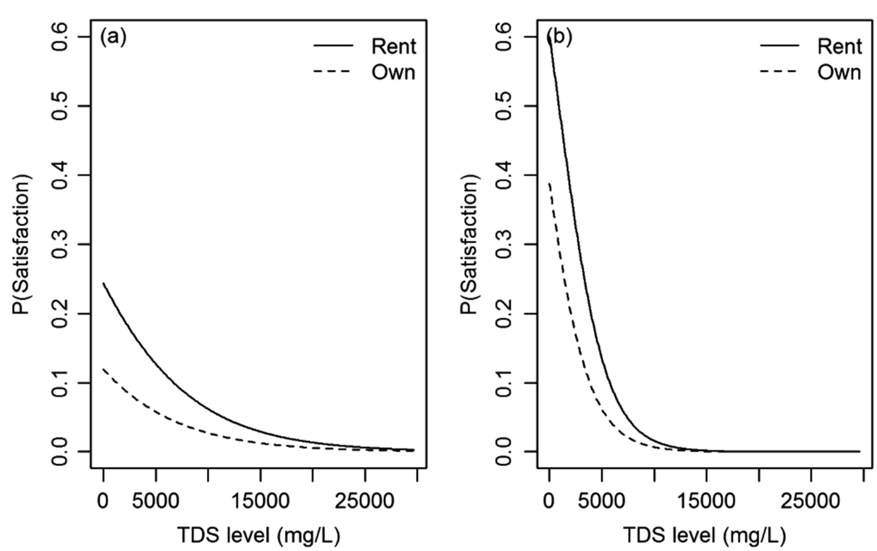

Fig. 5 Predicted probabilities of satisfaction as a function of TDS levels while accounting for the effect of resident ownership (respondent age was fixed at 20 years) across the dry season (**a**) and the wet season (**b**)

softeners, reverse osmosis, and ozonation) on one hand and the respondents' perception of well and public water quality on the other were tested. These salient socio-economic and contextual indicators proved to be statistically not significant in predicting respondents' perceptions. Previous work was inconclusive with regards to the influence of these factors on public perception. The increase in income has often been linked to higher environmental concerns (Hudon et al. 1991; Turgeon et al. 2004), although Dogaru et al. (2009) witnessed the opposite when assessing perception in a mining community in Romania and Syme and Williams (1993) reported inconclusive results in Australia. Similarly, education has been cited to be an important factor influencing environmental perceptions (Kraus et al. 1992; Dogaru et al. 2009); nevertheless Johnson (2003) found that the effect of education on tap water risk perception was insignificant while Turgeon et al. (2004) found that the effect of education was geographically variable. Overall the role that gender plays towards influencing perceptions has been reported to be weak (Doria 2010). Some studies have found it to be a significant factor (David 1971; Anadu and Harding 2000; Finucane et al. 2000; Griffin and Dunwoody 2000; Saylor et al. 2011), while others have failed to observe its importance (Griffin et al. 1998; Johnson 2003; Dogaru et al. 2009).

The effect of salinity on water quality perception was strong. A drop of ~1000 ppm in TDS increased the odds of a resident finding the water to be acceptable by nearly 17% in the dry season and by 57% during the wet season. Moreover, residents with TDS levels of ~500 ppm tended to be 2.1 and 8.5 times more satisfied with the water in the dry and wet seasons respectively, as compared to residents with TDS levels set to the overall average TDS value in the study area (~5200 ppm) (Fig. 5). The stronger impact that TDS levels has on satisfaction in the wet season as compared to the dry season may probably be due to the confounding effect that water scarcity has on satisfaction levels in the hot dry summer months. The fact that TDS proved to be a significant predictor of people's perception of their groundwater quality, while bacterial contamination did not is largely attributed to the fact that the former affects the flavor of the water (organoleptic) while the latter does not.

Concluding Remarks

In this study, we argued how poor water management in a coastal urban area facing water shortages and diminishing sustainable freshwater resources can exacerbate the latter by over-pumping and inducing further saltwater intrusion, underlining the limited resilience of coastal aquifers. The majority of the groundwater samples had TDS, total hardness, and chloride levels as high as 15 folds the recommended standards with high incidence of bacterial contamination, particularly total coliforms. The water satisfaction models highlight the main physio-chemical and socio-economic factors that play a critical role in shaping residents' perceptions towards the water quality. While a strong correlation between people's perception and groundwater quality is evident, the perception of the public water supply network proved to be independent of the measured quality of the network and the tap water. In fact, groundwater salinity levels were a major factor affecting people's satisfaction with the water quality of the public water supply network in the dry season. This mismatch between the actual network water quality, which can be objectively quantified with scientific indicators, and individuals' perceptions is largely driven by the difficulty to recognize the true source of water running in their taps. Pumping at will and the instantaneous mixing of groundwater with the incoming network water in building storage tanks conceals the quality of the latter and negatively affects people's perception of it. Moreover, the importance of prior experiences on developing perceptions can play an important role in explaining this disparity (Pickens 2005; Doria 2010). The consumption of tap water dominated with unregulated groundwater pumping, high in TDS and often polluted, when the public network water is in short supply influences people's perception of the network water. As such, satisfaction with network water doubled in the wet season, when the rates of groundwater pumping drop. Interestingly, our findings showed that respondents tended to still report a higher satisfaction with regards to the quality of their public water supply as compared to their well water. This might at first appear to contradict the paradigm that states that water quality perceptions tend to improve as the users' control over their water sources strengthens (Doria 2010); yet one can argue that the saltwater intrusion in the study area appears to erode the importance of this factor. While our respondents do have control over their well operations, their overall control over the salinization of the aquifer is minimal.

Failing to account for the perspectives that respondents have formed with regards to the quality of their public water supply can possibly stimulate increased reliance on the unregulated groundwater wells. Moreover, if the public believes that the quality of the public water supply is similar to the saline well water, subscription rates may also drop. Alarmingly, the survey showed that up to 5% of respondents have already taken steps to abandon the public water provider by investing in small-scale reverse osmosis desalination units to treat their brackish groundwater. Unfortunately, negative public perceptions developed on water quality have been shown to have a tendency to persist over time (McDaniels et al. 1998). As such, it is imperative that the water establishment works on increasing public awareness by providing them with information on the quality of distributed water and the dangers of mixing it with groundwater from unregulated wells. For this purpose, a media campaign coupled with a water quality monitoring plan that samples at various junctions along the network beyond the central treatment plant is a priority. Such a campaign ensures that water quality data are made available to the public on a regular basis. Providing information to residents has been shown to improve trust towards the water provider and change public perceptions (Doria 2010). Changes in perceptions can also be beneficial towards increasing people's propensity to engage in water conservation activities and support expenditure in new water projects (McDaniels et al. 1998). Given the mega-projects that the water establishments in Lebanon are embarking on over the next 10 years, it is more important than ever to initiate this process promptly. It is also hoped that the water establishment heeds the negative role that TDS has on the public's perception of their water quality. As such, it's increasing reliance on brackish groundwater well to supplement dwindling spring water supplies in the dry season has to cease if it aims to win back its customers.

Organizing public awareness campaigns, informing the public about the water quality of the public water network, and improving existing infrastructure are all essential drivers towards realigning people's perceptions with the actual water quality (Canter et al. 1993; Jones et al. 2007; Saylor et al. 2011); yet under the current conditions such measures will fall short unless unregulated groundwater pumping is controlled. For this to happen, while additional sources of water (conventional and non-conventional) can bridge the demand-supply gap, it is critical to promote demand-based management measures such as tariff restructuring that reflects water use instead of the existing flat-rate.

Given that future scenarios for many coastal urban areas foresee socioeconomic and climatic changes that will aggravate existing situations and jeopardize the adaptation capacities that societies have evolved over time (Vörösmarty et al. 2000; McGranahan et al. 2007; McDonald et al. 2011; UNESCO 2012), water establishments will increasingly face mounting challenges of finding solutions to improve water quality, educate the public, and reduce water shortages. Providing a robust communication channel between institutions and the public coupled with increasing awareness are imperative towards improving water management (Jones et al. 2007; Hu and Morton 2011; Saylor et al. 2011).

Our analysis was limited by three main factors that include a low emphasis on quantifying the contextual setting of respondents at the household, building, and neighborhood level; the inability to directly sample the quality of the public water at the respondents due to the instantaneous mixing with groundwater, and failing to account for the risk perceptions and characterize the utility functions of the respondents. Future work should address these issues to gain a better understanding of these important factors. Moreover, future work should also monitor the evolution of public perception as new water sources are added to augment resources.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

References

American Public Health Association (APHA), American water works association (AWWA), and water environment federation (WEF) (2012) Standard methods of water and wastewater. 22 edition. American Public Health Association, Washington, D.C

Amery H (2000) Assessing Lebanon's water balance. In: Brooks DB, Mehmet O (eds.) Water Balances in the Eastern Mediterranean. International Development Research Centre, Otawa, Page 160

Anadu EC, Harding AK (2000) Risk perception and bottled water use. Journal of the American Water Works Association 92:82–92

Barraqué B (2003) Past and future sustainability of water policies in Europe. Natural Resources Forum 27:200–211. doi:10.1111/1477-8947.00055

Bou-Zeid E, El-Fadel M (2002) Climate change and water resources in Lebanon and the Middle East. J Water Resour Plan Manage 128:343–355

Bridge JS, Demicco RV (2008) Earth surface processes, landforms and sediment deposits. Cambridge University Press, Cambridge, UK

Briggs JC, Ficke JF (1977) Quality of rivers of the United States, 1975 water year; based on the national stream quality accounting network (NASQAN). Report 78–200, pp. 24–27

Brody SD, Highfield W, Peck BM (2005) Exploring the mosaic of perceptions for water quality across watersheds in San Antonio, Texas. Landsc Urban Plan 73:200–214

Canter LW, Nelson D, Everett J (1993) Public perception of water quality risks-influencing factors and enhancement opportunities. J Environ Syst 22:163–163

Celik E, Muhammetoglu H (2008) Improving public perception of tap water in Antalya city, Turkey. J Water Supply 57:109–113

Constantine K, Massoud M, Alameddine I, El-Fadel, M (2017) The role of the water tankers market in water stressed semi-arid urban areas:Implications on water quality and economic burden. Journal of Environmental Management 188:85–94. http://dx.doi.org/10.1016/j.jenvman.2016.11.065

David EL (1971) Public perceptions of water quality. Water Resour Res 7:453–457

Dogaru D, Zobrist J, Balteanu D, Popescu C, Sima M, Amini M, Yang H (2009) Community perception of water quality in a mining-affected area: a case study for the certej catchment in the apuseni mountains in Romania. Environ Manage 43:1131–1145

Döll P, Müller Schmied H, Schuh C, Portmann FT, Eicker A (2014) Global-scale assessment of groundwater depletion and related groundwater abstractions: combining hydrological modeling with information from well observations and GRACE satellites. Water Resour Res 50:5698–5720

Doria MdF (2010) Factors influencing public perception of drinking water quality. Water Policy 12:1–19

Doria MdF, Pidgeon N, Hunter PR (2009) Perceptions of drinking water quality and risk and its effect on behaviour: a cross-national study. Sci Total Environ 407:5455–5464

Doria MF, Pidgeon N, Hunter P (2005) Perception of tap water risks and quality: a structural equation model approach. Water Sci Technol 52:143–149

Edwards BD, Ehman KD, Poti DJ, Reichard EG, Tinsley JC, Rosenberg RJ, Land M (2009) Stratigraphic controls on saltwater intrusion in the dominguez Gap area of coastal Los Angeles. In: Lee HJ, Normark WR (eds). Earth science in the urban ocean: the southern California continental borderland. Geological Society of America, Boulder, CO

El-Fadel M, Alameddine I, Abou Najm M, Doummar J, Zurayk R, Massoud M, Chaaban J (2014) Climate change and saltwater intrusion along the Eastern Mediterranean: socio-economic vulnerability and adaptation. International Development Research Center, Ontario

El-Fadel M, Maroun R, Semerjian L, Harajli H (2003) A health-based socio-economic assessment of drinking water quality: the case of Lebanon. Manage Environ Qual 14:353–368

El-Fadel M, Zeinati M, Jamali D (2000) Water resources in Lebanon: characterization, water balance and constraints. Int J Water Resour Dev 16:615–638

El-Zein A, Nasrallah R, Nuwayhid I, Kai L, Makhoul J (2006) Why do neighbors have different environmental priorities? analysis of environmental risk perception in a Beirut neighborhood. Risk Anal 26:423–435

Finucane ML, Slovic P, Mertz CK, Flynn J, Satterfield TA (2000) Gender, race, and perceived risk: the'white male'effect. Health Risk Soc 2:159–172

Gleeson T, Wada Y, Bierkens MFP, van Beek LPH (2012) Water balance of global aquifers revealed by groundwater footprint. Nature 488:197–200

Gorden SF (2000) The water utility of 2050. Am Water Works Assoc J 92:40

Griffin RJ, Dunwoody S (2000) The relation of communication to risk judgment and preventive behavior related to lead in tap water. Health Commun 12:81–107

Griffin RJ, Dunwoody S, Zabala F (1998) Public reliance on risk communication channels in the wake of a cryptosporidium outbreak. Risk Anal 18:367–375

Hu Z, Morton LW (2011) US midwestern residents perceptions of water quality. Water 3:217–234

Hudon E, Zayed J, Lainesse D, Loranger S (1991) Habitudes de consommation de l'eau potable au Québec et perception du risque pour le consommateur. Sciences et techniques de L'eau 24:357–362

Hutton G, Haller L (2004) Costs and benefits of water and sanitation improvements at the global level. World Health Organization, Geneva

Jardine CG, Gibson N, Hrudey SE (1999) Detection of odour and health risk perception of drinking water. Water Sci Technol 40:91–98

Johnson BB (2003) Do reports on drinking water quality affect customers' concerns? Experiments in report content. Risk Anal 23:985–998

Jones AQ, Dewey CE, Doré K, Majowicz SE, McEwen SA, Waltner-Toews D, Henson SJ, Mathews E (2007) A qualitative exploration of the public perception of municipal drinking water. Water Policy 9:425–438

Kraus N, Malmfors T, Slovic P (1992) Intuitive toxicology: expert and lay judgments of chemical risks. Risk Anal 12:215–232

Larson K, White D, Gober P, Harlan S, Wutich A (2009) Divergent perspectives on water resource sustainability in a public–policy–science context. Environ Sci Policy 12:1012–1023

Lazo JK, Kinnell JC, Fisher A (2000) Expert and layperson perceptions of ecosystem risk. Risk Anal 20:179–194

Llamas MR, Martínez-Santos P (2005) Intensive groundwater use: silent revolution and potential source of social conflicts. J Water Resour Plan Manage 131:337–341

Lou J-C, Lee W-L, Han J-Y (2007) Influence of alkalinity, hardness and dissolved solids on drinking water taste: a case study of consumer satisfaction. J Environ Manage 82:1–12

Mahler RL, Lolley BA, Loeffelman KA (1999) Public attitudes about water quality in the HUA. University of Idaho, Moscow, ID

Margane A, Steinel A (2011) Protection of jeita spring. Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover

Massoud M, Maroun R, Abdelnabi H, Jamali I, El-Fadel M (2013) Public perception and economic implications of bottled water consumption in underprivileged urban areas. Environ Monit Assess 185:3093–3102

McDaniels TL, Axelrod LJ, Cavanagh N (1998) Public perceptions regarding water quality and attitudes toward water conservation in the lower Fraser Basin. Water Resour Res 34:1299–1306

McDonald RI, Green P, Balk D, Fekete BM, Revenga C, Todd M, Montgomery M (2011) Urban growth, climate change, and freshwater availability. Proc Natl Acad Sci 108:6312–6317

McGowan W (2000) Water processing: residential, commercial, light-industrial. 3 edition. Water Quality Association, Lisle, IL

McGranahan G, Balk D, Anderson B (2007) The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environ Urban 19:17–37

McGuire MJ (1995) Off-flavor as the consumer's measure of drinking water safety. Water Sci Technol 31:1–8

Means EG (2002) Drinking water quality in the new millennium: the risk of underestimating public perception. J Am Water Works Assoc 94:28

Ministry of Energy and Water (2010) National water sector strategy. Ministry of Energy and Water, Beirut

Ministry of Environment (2011) State and trends of the lebanese environment. Ministry of Environment, Beirut

Nasr J, Jurdi M, Chaaya M, El Fadel M (2012) Actual and perceived water quality in one of Beirut's main settings: a comparative approach. International. J Water Resour Environ Manage 3:33–40

Owen AJ, Colbourne JS, Clayton CRI, Fife-Schaw C (1999) Risk communication of hazardous processes associated with drinking water quality—a mental models approach to customer perception, part 1—a methodology. Water Sci Technol 39:183–188

Pahl-Wostl C (2002) Towards sustainability in the water sector—the importance of human actors and processes of social learning. Aquat Sci 64:394–411

Park E, Scherer CW, Glynn CJ (2001) Community involvement and risk perception at personal and societal levels. Health Risk Soc 3:281–292

Parkin R, Balbus J, Waters W, Willnat L, Rivera I, Rivera-Torres E, Caparas M (2001) Vulnerable subpopulations' perceptions and use of drinking water.In: Annual meeting of the american water works association: new horizons in drinking water. American Water Works Association, Washington, DC

Pickens J (2005) Attitudes and perceptions. In: Borkowski N ed. organizational behavior in health Care. Jones and Bartlett Publishers, Sudbury MA pp 43–75

Postel SL (2000) Entering an era of water scarcity: the challenges ahead. Ecol Appl 10:941–948

Core Team R (2015) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

Rodriguez-Sanchez C, Sarabia-Sanchez FJ (2016) Perceived risk of urban water consumption: scale development, validation and characterisation in Spain. Urban Water J:1–7

Rojas LFR, Megerle A (2013) Perception of water quality and health risks in the rural area of Medellin. American. J Rural Dev 1:106–115

Saylor A, Prokopy LS, Amberg S (2011) What's wrong with the Tap? Examining perceptions of tap water and bottled water at Purdue University. Environ Manage 48:588–601

Smith DG, Cragg AM, Croker GF (1991) Water clarity criteria for bathing waters based on user perception. J Environ Manage 33:285–299

Syme GJ, Williams KD (1993) The psychology of drinking water quality: an exploratory study. Water Resour Res 29:4003–4010

Tang Z, Hong S, Xiao W, Taylor J (2006) Impacts of blending ground, surface, and saline waters on lead release in drinking water distribution systems. Water Res 40:943–950

Turgeon S, Rodriguez MJ, Thériault M, Levallois P (2004) Perception of drinking water in the Quebec city region (Canada): the influence of water quality and consumer location in the distribution system. J Environ Manage 70:363–373

United Nations Educational Scientific and Cultural Organization (2012) Groundwater and global change: trends, opportunities and challenges. United Nations World Water Assessment Program, Paris

United States Environment'al Protection Agency (2015) National secondary drinking water regulations. USEPA, Washington, DC

Vörösmarty CJ, Green P, Salisbury J, Lammers RB (2000) Global water resources: vulnerability from climate change and population growth. Science 289:284–288

Wakefield SE, Elliott SJ, Cole DC, Eyles JD (2001) Environmental risk and (re) action: air quality, health, and civic involvement in an urban industrial neighbourhood. Health Place 7:163–177

Wedgworth JC, Brown J, Johnson P, Olson JB, Elliott M, Forehand R, Stauber CE (2014) Associations between perceptions of drinking water service delivery and measured drinking water quality in rural Alabama. Int J Environ Res Public Health 11:7376–7392

World Health Organization (2003) Chloride in drinking-water: background document for development. World Health Organization, Geneva

World Health Organization (2011a) Guidelines for drinking-water quality. WHO Press, World Health Organization, Geneva

World Health Organization (2011b) Hardness in drinking-water: background document for development. World Health Organization, Geneva

Yamout G, El-Fadel M (2005) An optimization approach for multisectoral water supply management in the greater Beirut area. Water Resour Manage 19:791–812

Zektser S, Loáiciga HA, Wolf JT (2005) Environmental impacts of groundwater overdraft: selected case studies in the southwestern United States. Environ Geol 47:396–404